4755

U.S. Army
Environmental
Center

THICKENING OF CLAY SLURRIES BY PERIODIC PRESSURE FLOW THROUGH A POROUS POLYPROPYLENE TUBE

REPORT NUMBER
SFIM-AEC-TS-CR-93124

OCTOBER 1993

DISTRIBUTION STATEMENT A
Approved for Public Release
Distribution Unlimited

Prepared by:

George G. Chase and Sesh K. Kodavanti
Department of Chemical Engineering
The University of Akron
Akron, Ohio 44325-3906

Prepared for:

US ARMY ENVIRONMENTAL CENTER
Edgewood Area
Aberdeen Proving Ground
Maryland 21010-5401

THICKENING OF CLAY SLURRIES BY PERIODIC PRESSURE FLOW THROUGH A POROUS POLYPROPYLENE TUBE

by

George G. Chase and Sesh K. Kodavanti
Department of Chemical Engineering
The University of Akron
Akron, Ohio 44325-3906

for

U.S. Army Environmental Center
Aberdeen Proving Ground
Maryland 21010-5401

October 1993

Contract No. DAAL03-91-C-0034
TCN Number: 92-513
Scientific Services Program

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	October 1993	Final Report, From: 10/1/92 To: 9/30/93

4. TITLE AND SUBTITLE

Evaluation of the Dual -Functional filter in thickening slurries.

5. FUNDING NUMBERS

Contract DAAL 03-91-C-0034

6. AUTHOR(S)

George G. Chase and Sesh Kodavanti

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Department of Chemical Engineering
The University of Akron
Akron, OH 44325-3906

8. PERFORMING ORGANIZATION REPORT NUMBER

Delivery Order 832

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Army Research Office
PO Box 12211
Research Triangle Park, NC 27709

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

TCN 93307

11. SUPPLEMENTARY NOTES

Task was performed under a scientific services agreement issued by Battelle, Research Triangle Park Office, 200 Park Dr. PO Bx. 12297, Research Triangle Park, NC 27709

12a. DISTRIBUTION / AVAILABILITY STATEMENT

~~May not be released by other than sponsoring organization without approval of the U.S. Army Research Office.~~

12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200 words*)

In this work a periodic pressure filtration process is evaluated to determine (1) if the process can be used to thicken clay slurries, and (2) to obtain an order of magnitude cost estimate of the process for comparison with other thickening processes. Current environmental clean-up operations, such as soil washing, result in large volumes of dilute slurries that must be filtered to remove the particles. The soil particles collected during the filtration, if clean, can be returned to the ground. One step in the dewatering and filtering process is thickening the slurry before filtering. The periodic pressure filtration process is one possible process for thickening clay slurries but no performance data is available for evaluating the process. In this work a one-tube periodic pressure filter process is evaluated by measuring the thickened slurry discharge and filtrate rate while varying the design and operating parameters. The experimental results show that the process does thicken the slurries of 1 to 3% inlet mass concentration to about 30 to 40 % mass concentration. Using this performance data the cost estimate shows that scale-up of the process to a bank of tubes would be much more expensive than the cost of a typical gravity thickener. Hence, the periodic pressure filter should only be used for materials that do not settle well or if the size of the gravity thickener is excessively large.

14. SUBJECT TERMS

Filtration, Gravity Thickening, Clay, Soil Washing

15. NUMBER OF PAGES

38

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
			-

TABLE OF CONTENTS

LIST OF FIGURES

ACKNOWLEDGMENTS

This work was supported by the U.S. Army Environmental Center (Mr. Wayne Sisk) under the auspices of the U.S. Army Research Office Scientific Services Program administered by Battelle (Delivery Order 832, Contract No. DAAL03-91-C-0034).

SECTION 1

EXECUTIVE SUMMARY

In this work a periodic pressure filtration process is evaluated to determine (1) if the process can be used to thicken clay slurries, and (2) to obtain an order of magnitude cost estimate of the process for comparison with other thickening processes.

Current environmental clean-up operations, such as soil washing, result in large volumes of dilute slurries that must be filtered to remove the particles. The soil particles collected during the filtration, if clean, can be returned to the ground. One step in the dewatering and filtering process is thickening the slurry before filtering. The periodic pressure filtration process is one possible process for thickening clay slurries but no performance data is available for evaluating the process.

In this work a one-tube periodic pressure filter process is evaluated by measuring the thickened slurry discharge and filtrate rate while varying the design and operating parameters.

The experimental results show that the process does thicken the slurries of 1 to 3% inlet mass concentration to about 30 to 40 % mass concentration. Using this performance data the cost estimate shows that scale-up of the process to a bank of tubes would be much more expensive than the cost of a typical gravity thickener. Hence, the periodic pressure filter should only be used for materials that do not settle well or if the size of the gravity thickener is excessively large.

SECTION 2

INTRODUCTION

2.1 PROBLEM STATEMENT

Increasingly, water treatment systems are being called upon to produce effluents of substantially higher quality. One of the major objectives of water treatment is the removal of fine particles. The purpose of this work is to evaluate the proof of concept of using a porous tubular filter in periodic pressure driven flow to thicken dilute clay slurries.

2.2 TECHNOLOGICAL SIGNIFICANCE

Micron and sub micron particles frequently occur by accident or by design in many fluid process streams. When these particles are hazardous materials it becomes especially important to remove them to prevent contamination of the environment. For example, the production of explosives at Army ammunition plants can result in fine particles of 2,4,6-trinitrotoluene (TNT), hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX), and octahydro-1,3,5,7-tetrazocine (HMX) in waste streams. The removal of the particles from these waste streams normally requires multiple stages of filters, thickeners, and/or settlers[1].

As another example, the washing of soils to remove contaminants also produces waste streams that contain wide ranges of particle sizes. Multiple stages of filters and solid/liquid separators are again required to produce a wash water that can be reused or returned to the environment and to reconstitute the soil so that it may be returned to the ground[2].

The cost of separating particles from liquids vary widely depending on the materials and the type of equipment. As a generalization, two of the most significant factors are the total volume of slurry to be filtered and the manpower or labor required to operate the process. Filter presses, centrifuges, and other filtering devices can be automated to reduce labor costs[3,4] but at a significantly increased capital cost. Settling ponds may be the least labor intensive to operate, but the trade off is the size required for the ponds and the periodic dredging that is required. In each of these cases, the processes can benefit by a reduced volume of slurry.

Slurries can be thickened such as by a continuous gravity thickener[3,4], by continuous cross flow filtration through a porous membrane tube[4], or by a periodic pressurized filtration flow through a porous tube as applied in this work.[5] The periodic pressure flow device can potentially thicken the slurry to greater concentrations than the cross flow filter but requires more expensive control valves. The continuous gravity settler may thicken the slurry to greater concentrations than the periodic pressure flow device but mechanically it is much more complex due to rotating rakes.

2.3 SCOPE OF THE WORK

The project duration of this work was limited to one year to prove the concept of periodic pressure flow in a porous tube for thickening clay slurries. The work includes designing and setting up an experimental apparatus to test the concept and to obtain experimental data.

Ultimately, the apparatus could be used for dewatering slurries such as from soil washing processes. An order of magnitude cost estimate for scale-up is included in this work to provide a basis from which to compare designs.

Given the time constraint on the project duration, experiments were limited to varying only selected parameters. The meaning of these parameters are explained further in the experimental setup in Section 4. These parameters include:

- Applied pressure
- pH of the water
- Residence time in the tube
- Annular space within the tube.
- Inlet slurry concentration

There are many other parameters that also could have been varied, but the above are sufficient to prove the concept. Parameters held constant are:

- One type of clay (Kaolin)
- Discharge time
- Porous tube material (polypropylene)
- Temperature
- Liquid phase (water)
- Tube length
- Tube diameter

Any future work with this apparatus should evaluate the effects of varying these latter quantities. In particular, experiments should be conducted on actual washed soils.

2.4 SUMMARY OF RESULTS

Experiments were run on dilute clay slurries of 1 and 3% mass concentrations. The thickened slurry concentrations ranged from 7 to over 90 % by mass in the experiments. Most commonly the thickened slurry discharge concentration was in the range of 30 to 40 % by mass. The differences in performances between the two inlet slurry concentrations were not significant for the most part.

The thickened discharge concentration increased slightly with applied pressure and residence time in the tube indicating a weak functional dependence. Slurry with a pH of about 7.62 (tap water) produced better results than a slurry with a pH of 8.2.

The most concentrated discharge was obtained with the 1/4 inch diameter aluminum rod in the tube, however for the best filtrate rate no rod should be used.

The cost estimate for scale up to a bank of tubes is based upon the cost of the materials and equipment to operate the one-tube experiment. The requirement of two solenoid valves per tube contributes the most to the cost of the process. Using typical rate data from the experiments about 16 tubes are needed to produce about one ton of thickened slurry per day. The cost of materials and equipment for this process is about $8000.

By comparison, a gravity thickener can be expected to cost from $600 to $4000. This shows that the periodic pressure filtration process is much more expensive than the typical gravity thickener. The periodic pressure filtration should only be used in cases in which particles do not settle or the size of the gravity thickener is excessively large.

SECTION 3

COMPARISON OF FILTRATION PROCESSES

The periodic pressure filtration that is the subject of this work has similarities with the more common dead-end filtration (*i.e.* cake filtration), cross-flow filtration, and the not-so-common dual-functional filtration. Brief descriptions for each of these filtration processes are given in this section for comparison with the periodic pressure filtration process. More extensive descriptions of the processes are available in the cited literature.

Initially, the proposed work was to evaluate the use of the dual-functional filter for thickening clay slurries. However, during testing it became clear that the thickening of clay slurries does not need to be limited to very thin cakes on the tube walls as required by the dual-functional filter. As a result, the process was modified to the periodic pressure filtration.

3.1 DEAD-END FILTRATION

Dead-end filtration is the commonly applied to form filter cakes. In cake filtration, particles are deposited on the surface of a relatively thin permeable filter medium by the principle of screening. As soon as the initial layer of cake forms on the surface, the deposition of particles occurs on the surface of the cake and the medium acts as a support. The fluid flow is through the cake and the medium. As the cake builds up the resistance to fluid flow increases and this requires a greater applied pressure drop to maintain the flow.

As shown in Figure 3-1, the cake continually builds up over time normal to the medium surface. Unless the cake growth is limited by some artificial means, the resistance continues to increase over time as the cake depth increases until the flow decreases to very low rates. If the particles are very small then a small cake thickness can produce a large resistance which makes thick cakes impractical.

After the cake is formed and the process is stopped, then the cake must be removed. This is done, for example, by opening up a filter press and letting the cake fall off of the medium or by scraping the cake off.

In most cases when a "dry" cake with high solids concentration is desired, a dead-end filtration is used. The feed concentration of the inlet slurry has a profound effect on the cycle time and production rate of the filter and *pre thickening* can be of great benefit. The effect of slurry concentration on solids yield can be easily demonstrated using the following equation derived in appendix I of Svarovsky[9] (neglecting medium resistance):

$$Y = \left(\frac{2 \Delta P f c}{\alpha \mu t_c} \right)^{1/2}$$

where ΔP is the pressure drop, c is the feed solids concentration, α is the specific cake resistance, μ is the liquid viscosity, Y is the solids yield (dry cake production in kg/m^2/s), f

is the ratio of the filtration to cycle time, and t_c is the cycle time. For the same cycle time, if the concentration is increased by a factor of four, production capacity is doubled. In other words, filtration area can be halved for the same capacity.

One additional benefit of pre thickening is the reduction in cake resistance. If the feed concentration is low, there is a general tendency of particles to pack together more tightly, thus leading to higher resistance to flow. However, with thicker concentrations many particles approach the filter medium at the same time. They may bridge over the pores which reduces the particle penetration and a more permeable cake is formed.

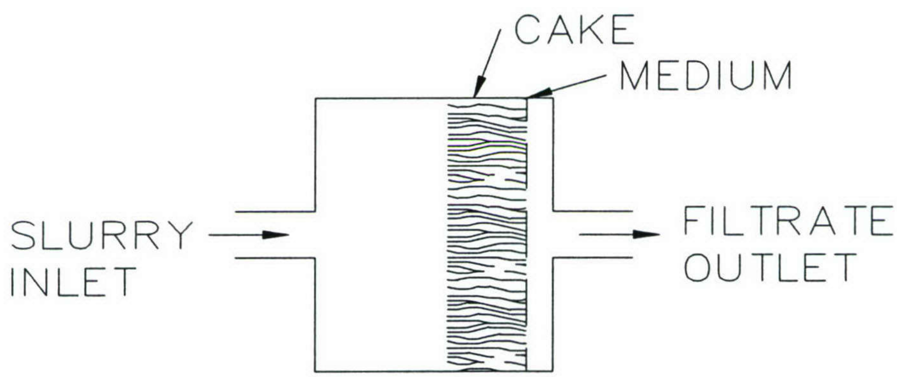

Figure 3-1. Dead-end filtration in which particles are stopped by the screening them out of the slurry. The filtrate can be discarded or sent to another tank for storage.

3.2 CROSS-FLOW FILTRATION

One method of pre thickening the slurry is the cross flow method[3,4,6,7,8] in which the slurry flows at a high velocity parallel to the surface of the filter medium. This is shown in Figure 3-2 which represents a cross-section of a rectangular or tubular membrane. By this means the cake is prevented from forming during the early stages of the filtration. This can be particularly beneficial when the slurry is flocculated and exhibits shear-thinning non-Newtonian properties.

The slurry is recirculated through the cross flow filter and back to the supply tank as shown in Figure 3-3. Typical recirculation rates may be 10 to 20 times the filtrate rate. In cases where a dilute solution containing small quantities of solids which tend to blind the filter cloth is to be filtered, cross-flow filtration is extensively used. It is the normal mode of operation for ultrafiltration using membranes.

Some advantages of cross-flow filtration over the conventional dead-end filtration are:

1. A higher overall liquid removal rate is achieved by prevention of the formation of an extensive filter cake.
2. The process feed remains in the form of a mobile slurry suitable for further processing.
3. The solids content of the product slurry may be varied over a wide range.
4. It may be possible to fractionate particles of different sizes.

The flow diagram shown in Figure 2-3 is one likely to be used for batch processing; it is in essence a basic pump recirculation loop. The process feed is concentrated by pumping it from the tank and across the filter membrane. The partially concentrated slurry exiting the membrane is recycled back to the tank for further processing while the filtrate is stored or discarded as required.

In practice, the filtrate rate falls with time due to membrane fouling. The fouling occurs as particles block the pores in the membrane surface. The rate of fouling depends upon the materials being processed, the membrane used as the filter medium, the cross flow velocity, and the applied pressure.

Eventually, the slurry concentration builds up until the high velocity for cross flow cannot be maintained. The filtration is stopped before the cake build up in the filter makes cake removal difficult.

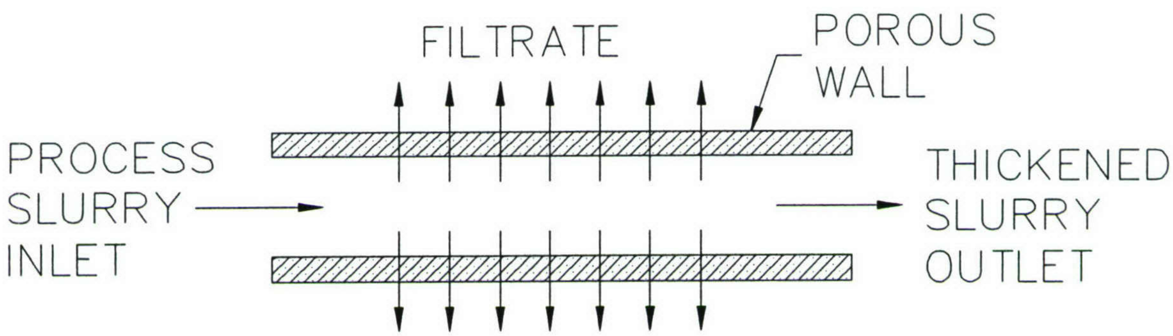

Figure 3-2. Cross-Flow filtration. The slurry flows parallel to the filter medium and prevents significant build-up of cake.

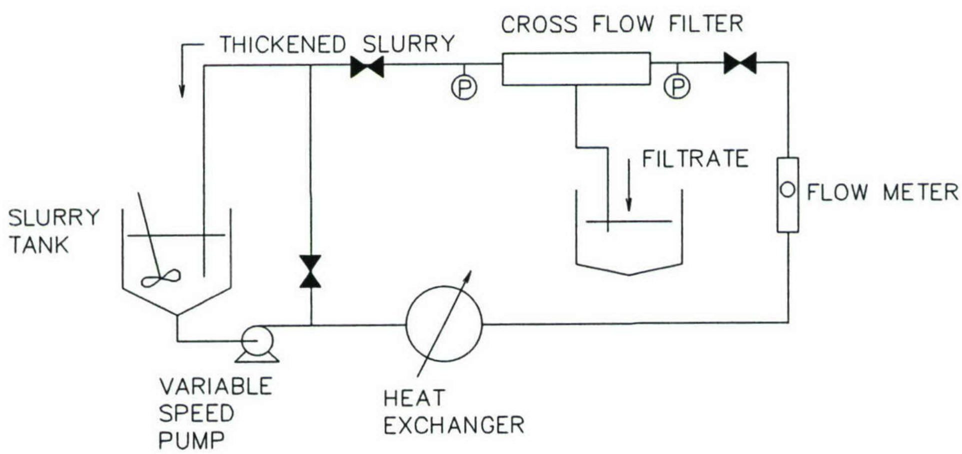

Figure 3-3. Flow diagram for a simple cross-flow filtration process. As the slurry passes through the cross flow filter the solids concentration increases. The slurry is recycled back to the slurry supply tank where the total slurry supply concentration gradually increases.

3.3 DUAL-FUNCTIONAL FILTER

The dual-functional filter makes use of filtration and settling to thicken the slurry.[5] As shown in Figure 3-4, the filtration occurs in a long tube in which a thin cake is formed on the inside of the tube walls. The thin cake and slurry are discharged from the tube into a receiving vessel where the cake settles to the bottom and the liquid is decanted.

The filtration cycle has three phases: a filtration phase, a dump phase, and a settling phase. The filtration phase starts with the introduction of slurry at the top of the long tube and the valve closed at the bottom of the tube. The filter cake forms on the interior wall of the tube and filtrate passes through the porous walls of the tube to be collected on the outside. The filtration phase stops before the cake fills the inside of the tube. The method of filtration is largely dead-end, though in the tube near the slurry inlet the flow rate may initially be large enough for the filtration to be cross-flow.

The dump phase of the cycle starts by closing the feed valve at the top of the tube and opening the discharge valve at the bottom. The resulting pressure release causes the cake and feed slurry in the vertical tube to dump into the receiving vessel. The discharged material consists of cake and a dilute slurry; the cake material does not completely redisperse into the slurry.

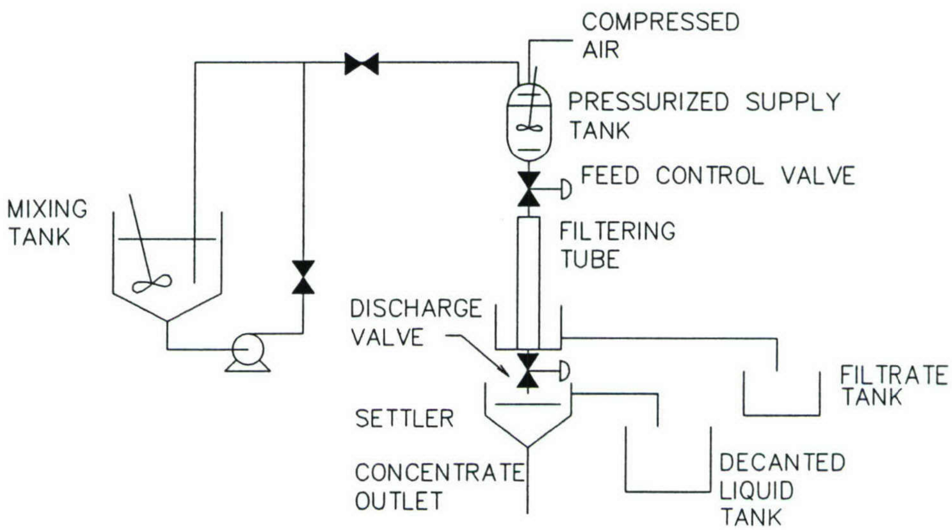

Figure 3-4. Dual-functional filter flow diagram.

The settling phase occurs in the receiving vessel. The cake material readily settles out of the discharge mixture from the tube. The liquid at the top of the settler contains some particles and can be recycled for filtering again.

The dual-functional filter has several process advantages:

1. The rapid cycle of the process produces high filtration rates because the cake does not accumulate to large thickness on the wall.

2. There is no mechanical device required to remove the cake from the walls of the tube.
3. The combination of filtration and settling provides a high degree of thickening of the sludge.
4. Filter aid is usually not needed.
5. The process is mechanically simple and is not labor intensive.

Henry *et.al.*[5] tested the dual-functional filter on neutralized acid mine drainage water and observed thickening of the slurry from 0.2% by weight of solids at the feed inlet to 35% weight of solids after decanting. They also developed a model for predicting the cake build-up on the inside of the tube and the overall filter performance.

3.4 PERIODIC PRESSURE FILTRATION

Periodic pressure filtration is very similar to the dual-functional filter except that the tube is much shorter and near the bottom of the tube the cake is allowed to fill the tube as shown in Figure 3-5. As a result concentrated slurries are possible without the need for the settler shown in Figure 3-4 though a settler could be used if further thickening is desired.

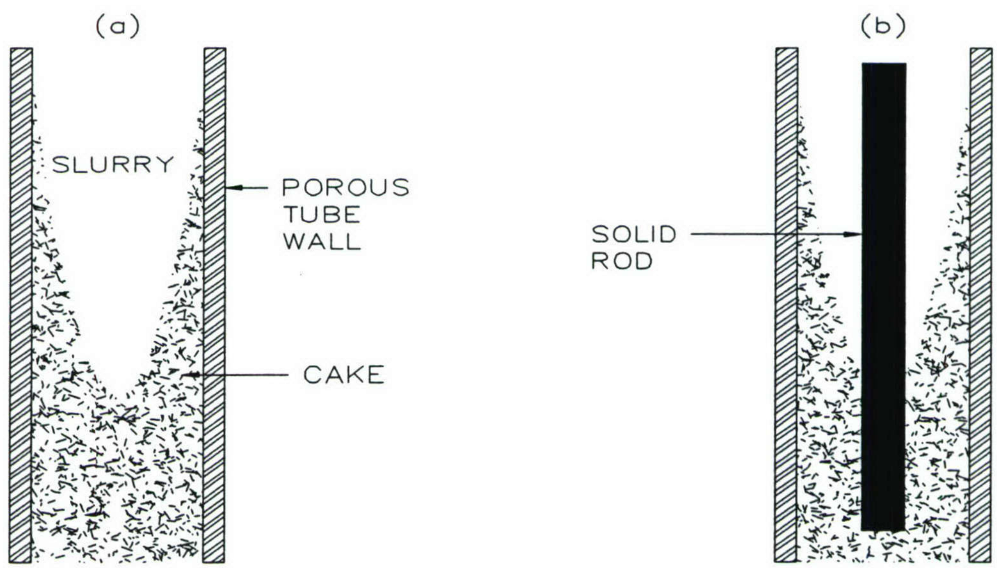

Figure 3-5. Periodic pressure filtration forms a cake on the inside tube wall. As shown in (a) the filter cake forms on the wall and the slurry occupies the center of the tube. Near the tube exit at the bottom of the tube the cake fills the inside cross-section of the tube. In (b) a solid rod is placed in the center of the tube to reduce the volume occupied by the slurry.

The exiting slurry concentration depends largely upon the relative volumes of cake and slurry within the tube. One obvious way of reducing the ratio of slurry volume to cake volume is to reduce the space available for the slurry. This is done by inserting a solid rod within the tube, as shown in Figure 3-5. As a result, the cake forms within the annular space. There is a trade-off in designing the filter this way, while the exiting slurry may be more concentrated, if the annular space is made too small the cake will not readily eject from the tube.

Using a set-up similar to that in Figure 3-4 for the dual-functional filter, the periodic pressure filter has a feed inlet valve and discharge valve which control the operation. When the inlet valve is open and the discharge valve is closed the slurry enters the tube and cake forms on the walls. When the feed valve is closed and the discharge valve is open the pressure within the tube and gravity cause the cake to flow downward.

Some techniques could be applied to enhance the operation but were not attempted in this current work. These include:

- Apply air pressure at the top of the tube to force more of the cake out of the tube at the discharge part of the cycle.
- Apply a back pressure of air from the outside of the tube inward to dislodge the cake from the walls of the tube.
- Efflux time for cake discharge can be varied to find an optimum.

Currently, there is no theory for predicting the performance of a periodic pressure filtration. Qualitatively the periodic pressure filtration should work for it has many similarities with existing filter processes. Like the dual-functional filter, it is largely a dead-end filtration with possible cross-flow filtration occurring early in the filtration cycle near the feed inlet. Proving that it does work on clay slurries is the subject of the experimental portion of this report.

SECTION 4

EXPERIMENTAL SETUP AND PROCEDURES

In this section the experimental setup and procedures are discussed on how the experiments were run. The experiments were designed to investigate the effects of varying the applied pressure, pH of the water, solid rod diameter, residence time in the tube for the filtration part of the cycle, and inlet slurry concentration. Details on the specific experiments and the results are in Section 5.

4.1 EXPERIMENTAL SETUP

The experimental setup is shown in Figure 4-1. The slurry is prepared in the mixing tank and then is pumped into the pressurized tank for the filtration. Air pressure provides the applied pressure driving force for the filtration. The slurry exits the pressurized tank and passes through a pump which circulates the slurry back into the pressurized tank. This circulation keeps the slurry well suspended in the pipe lines during the experiments.

Part of the slurry is diverted into the filtering tube when the feed inlet valve is open. The cake forms in the tube and the filtrate passes through the tube wall and is collected in the filtrate tank. At the end of the residence time in the tube the feed valve closes and the discharge valve opens. The cake and slurry in the tube is dumped into the thickened slurry tank.

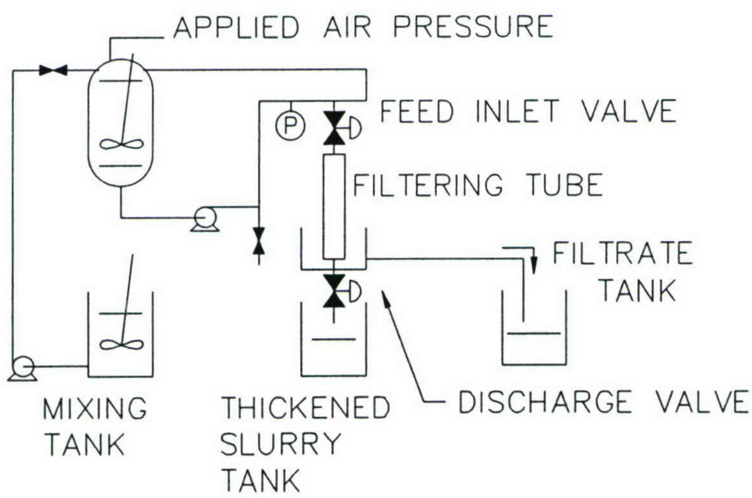

Figure 4-1. Experimental setup for periodic pressure filtration.

The slurry concentration is determined by collecting a sample of the slurry from a sampling valve as it exits the pump and cycles back to the pressurized tank. The pressure is measured directly from a gauge in the slurry feed line. The mass of filtrate and mass of thickened slurry are measured with a weighing scale.

The operation of the filter is controlled by the feed inlet valve and the discharge valve. These valves must be synchronized to keep dilute slurry from passing through the filtering tube and into the thickened slurry tank. Solenoid valves were chosen for this purpose because they can be controlled by electrical signals, which in turn are controlled by a computer (not shown in Figure 4-1).

The solenoid valves used in the experiments are nominal 1/2 inch pipe size valves, number Hayward 120 volt 19 watt solenoid valves supplied by Corro-Flo Engineering in Westerville, Ohio. The filtering tube is made of porous polypropylene (approximate pore size of 2 microns according to supplier) manufactured by General Polymeric Corporation, Reading, PA. The tube is 32 inches long, 2 inches outside diameter and 1 inch inside diameter.

The solid rods used in the experiments are made of aluminum. The rods and tube are machined with a support bracket so that the rod hung straight down in the tube and is supported only from the top. The support bracket has holes in it that allows the dilute slurry to pass through. This is shown in Figure 4-2. The rod is supported only from the top to minimize interference of the cake discharge by the rod.

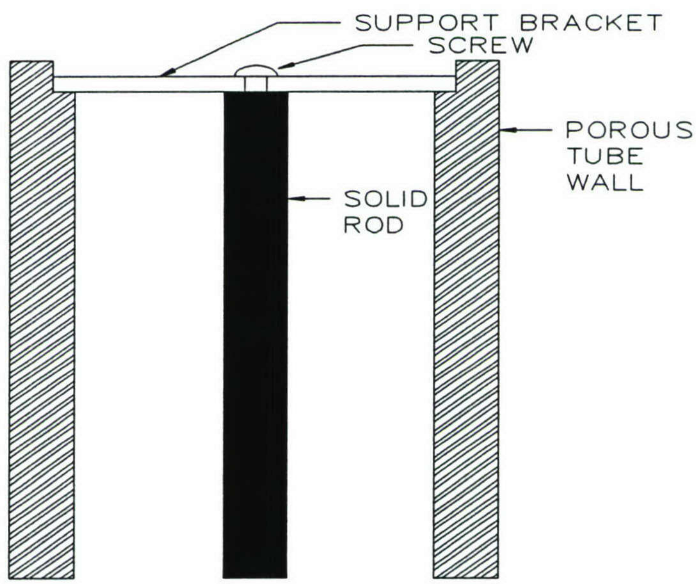

Figure 4-2. Machined support bracket holds aluminum rod in the center of the filtering tube. A screw in the center of the bracket holds the rod in place. The bracket is a circular disk with holes drilled into it (not shown) for the slurry to flow through. The bracket is slightly larger in diameter than the inside diameter of the filtering tube. A notch is machined into the filtering tube at the top to receive the support bracket.

The polyethylene walls of the filtering tube are a relatively soft material that may not hold up well to machine threads. Instead of threading the ends of the tube to attach to the pipes, upper and lower endcaps were machined to hold the tube in compression. This is shown in Figure 4-3. The endcaps are made of transparent Plexiglas that are machined to hold the tube and a rubber gasket. The endcaps hold the polyethylene tube in compression through four 5/16 inch threaded rods that are spaced around the tube. Filtrate passing through the walls of the porous tube is collected in a large Plexiglas tube mounted onto the lower endcap. The filtrate then passes through a fitting and into a 1/2 inch pipe which carries it to the filtrate collection tank.

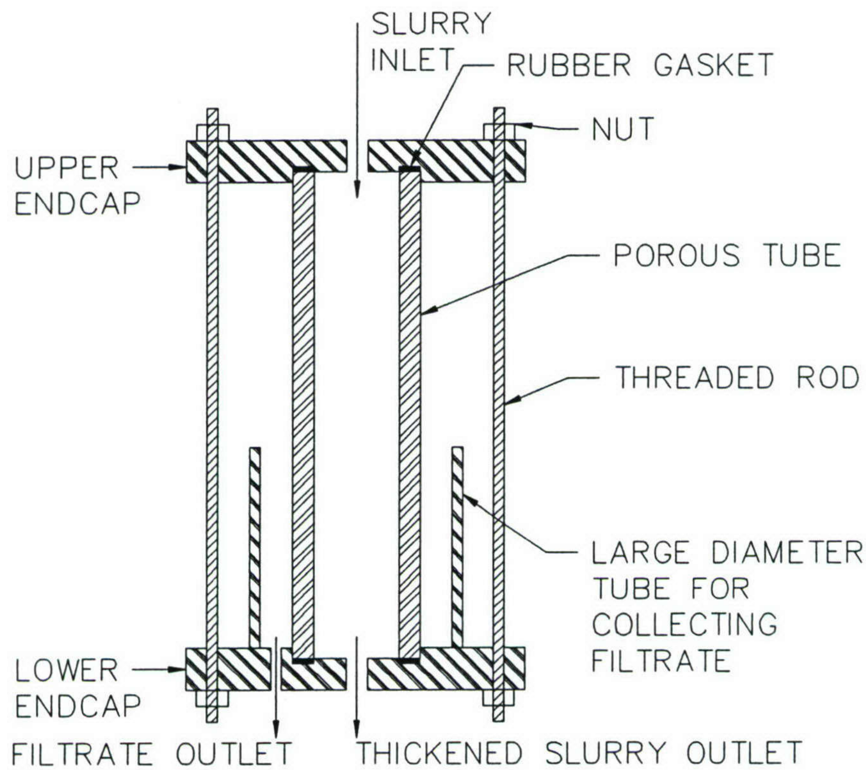

Figure 4-3. Sectional view of porous tube held in compression between two endcaps.

4.2 PROCEDURES

The general procedures for the experiments are described here. About 70 liters of slurry is prepared by mixing kaolin clay (supplied by the Charles B. Crystal Co., New York, NY) with tap water in the mixing tank in Figure 4-1. Any additives to control the pH are also added at this time. Sulfuric acid, H_2SO_4, is used to lower the pH and sodium hydroxide, NaOH, is used to raise the pH in the experiments. The slurry mixture is mixed for about 1 hour in the mixing tank and then it is pumped into the pressurized tank.

In the pressurized tank the air pressure is raised to the experimental setpoint and the slurry is agitated with an impeller. The slurry is pumped through the pipe line past the filter and back into the pressurized tank for about an hour to ensure thorough mixing. Samples of the slurry are removed through a sampling valve and analyzed for the actual pH and slurry concentration. This sampling is done to account for any residual materials that may have been left in the system from a previous experiment.

Control of the experiment is turned over to the computer which opens and closes the feed inlet valve and the discharge valve. First the feed inlet valve is opened to allow slurry to enter the filter tube. After a specified residence time the feed inlet valve is closed and the discharge valve is opened. In all of the experiments the discharge valve was opened for 15 seconds while the residence time was varied in the experiments.

Initially the filtering tube is filled with air. This air must be displaced and cake formed on the walls before any meaningful measurements can be recorded. It was found that by holding the first cycle residence time to at least 4 minutes that the cake was adequately formed and thickened slurry measurements were reproducible after the second or third cycle.

The thickened slurry discharge concentration is determined by collecting the slurry in a small container. The mass of the slurry is determined by weighing, the slurry is dried in an oven, and the particle mass is weighed. The ratio of the weights gives the thickened slurry solids mass concentration.

After the slurry is collected for determining the concentration for a particular residence time or applied pressure, the residence time or applied pressure are changed for the next experiment. The measurement process is repeated. Including the back-to-back experiments the filtration was repeatedly operated for 1.5 to 2 continuous hours without any adverse affects.

To change the slurry concentration or the pH, it requires a complete change of the slurry in the tank and pipe system. The entire apparatus is rinsed out 5 times with tap water before loading in the new slurry.

The results of the experiments are in the next section.

SECTION 5

EXPERIMENTAL RESULTS AND DISCUSSION

5.1 EXPERIMENTAL RESULTS

The experimental results are tabulated in Table 5-1. A total of 117 experimental measurements were made by varying the applied pressure, pH, rod diameter, residence time, and slurry concentration. These parameters could have been varied over wider ranges and other parameters also could have been varied but the experiments that were run are sufficient to prove the concept. The values that are listed in Table 5-1 are the operating conditions for the experiments and the measured values.

The column in Table 5-1 with the heading "Thickened Mass" is the mass of the thickened slurry discharged from the tube in one cycle, the heading "Discharge Mass %" is the mass percent of clay in the sample of thickened slurry for that experiment after several cycles. The "Filtrate Mass" heading is the total mass of water that passed through the tube wall during the residence time when the cake was forming in the tube.

Only one experiment was attempted with an acidic solution (pH of about 6.5). In this experiment the filtrate rate was very slow. When the process switched to the discharge part of the cycle the cake and slurry blew out of the bottom of the tube under high pressure. Because of this the thickened slurry concentration could not be measured. It is suspected that under basic conditions the clay particles may flocculate, forming larger particles that are easier to filter. Under acidic conditions the individual clay particles do not flocculate and these particles may plug the pores in the tubes. This is consistent with similar observations reported in literature[10] on the behavior of clay particles.

Data points are taken from Table 5-1 and plotted for discussion in the next section. Some general observations are listed here on the conduct of the experiments:

1. Experiments were run back-to-back with the filter running continuously over periods of 1.5 to 2 hours without the tube becoming clogged.
2. When experiments were stopped, the tube had to be rinsed. Otherwise the cake hardened within the tube and had to be manually removed (usually by striking the outside tube wall).
3. In all cases the cake was viscous and stuck to the tube walls. However, during the operation of the filter the pressure within the tube and gravity were sufficient to make the cake flow downward and out of the discharge valve.
4. The 15 seconds discharge time was not long enough to discharge all of the cake from the tube.
5. The clay mixed very well with the water in the mixing tank. The agitator kept the clay particles well suspended in the tank. The slurry concentrations of 1 and 3 % by mass of clay were dilute enough that no pumping problems occurred.
6. No problems were observed with the solenoid valves in opening or closing on the thickened slurry.

7. It was observed that the solenoid valves became hot when operated for long periods of time. However, the temperature was within the specified manufacture limits.
8. The clay readily sticks to the aluminum rods when the rods were inserted into the tubes.
9. Since the aluminum rods were attached only at the top of the tube there is a possibility that the rod did not stay coaxial with the filter tube. Observations at the end of the experiments when the tube and rod were disassembled indicate that this was not a problem.

Table 5-1. List of experimental parameter values and measured values.

EXP NO.	$P_{APPLIED}$ PSI	pH	$t_{RESIDENCE}$ MINUTES	ROD DIA., IN	SLURRY CONC.,%	DISCHARGE MASS, g	DISCHARGE MASS %	FILTRATE MASS, g
1.	15	7.62	1	0	1	32.83	15.68	384.57
2.	15	7.62	3	0	1	46.08	13.72	618.94
3.	15	7.62	5	0	1	60.07	14.33	1144.97
4.	20	7.62	1	0	1	34.10	22.40	439.12
5.	20	7.62	3	0	1	38.37	18.80	847.45
6.	20	7.62	5	0	1	58.32	31.77	1190.16
7.	25	7.62	1	0	1	41.56	25.43	474.42
8.	25	7.62	3	0	1	55.44	20.32	850.39
9.	25	7.62	5	0	1	67.07	41.70	1221.32
10.	15	7.62	1	0	3	14.21	6.190	264.30
11.	15	7.62	3	0	3	12.56	12.84	551.87
12.	15	7.62	5	0	3	16.63	23.05	752.46
13.	15	7.62	7	0	3	15.16	22.90	1182.74
14.	20	7.62	1	0	3	23.21	25.03	373.55
15.	20	7.62	3	0	3	28.11	31.37	709.69
16.	20	7.62	5	0	3	47.31	49.24	1110.10
17.	20	7.62	7	0	3	53.82	52.17	1322.22
18.	25	7.62	1	0	3	35.30	22.40	417.95
19.	25	7.62	3	0	3	55.69	22.03	670.35
20.	25	7.62	5	0	3	35.64	19.02	1178.10
21.	25	7.62	7	0	3	45.38	19.87	1406.98
22.	15	7.62	1	1/8	1	43.77	14.40	151.40
23.	15	7.62	3	1/8	1	38.53	10.14	394.00
24.	15	7.62	5	1/8	1	36.47	-	544.10
25.	15	7.62	7	1/8	1	37.99	14.50	808.80
26.	20	7.62	1	1/8	1	41.14	19.95	311.50
27.	20	7.62	3	1/8	1	34.22	20.95	618.80
28.	20	7.62	5	1/8	1	40.25	23.42	924.60
29.	20	7.62	7	1/8	1	47.43	25.06	1178.80
30.	25	7.62	1	1/8	1	30.28	32.39	343.50

EXP NO.	$P_{APPLIED}$ PSI	pH	$t_{RESIDENCE}$ MINUTES	ROD DIA., IN	SLURRY CONC., %	DISCHARGE MASS, g	DISCHARGE MASS %	FILTRATE MASS, g
31.	25	7.62	3	1/8	1	48.96	29.69	596.70
32.	25	7.62	5	1/8	1	41.57	25.83	884.90
33.	25	7.62	7	1/8	1	48.16	26.66	1066.70
34.	15	7.62	1	1/8	3	24.50	20.81	197.70
35.	15	7.62	3	1/8	3	36.49	14.52	513.80
36.	15	7.62	5	1/8	3	13.40	44.77	755.40
37.	15	7.62	7	1/8	3	38.40	18.48	828.00
38.	20	7.62	1	1/8	3	22.30	26.45	220.50
39.	20	7.62	3	1/8	3	35.11	27.91	382.90
40.	20	7.62	5	1/8	3	38.01	25.81	709.30
41.	20	7.62	7	1/8	3	32.30	22.91	781.10
42.	25	7.62	1	1/8	3	39.96	21.62	208.20
43.	25	7.62	3	1/8	3	36.19	24.15	389.30
44.	25	7.62	5	1/8	3	38.39	23.73	484.40
45.	25	7.62	7	1/8	3	43.93	20.46	739.90
46.	15	7.62	1	1/4	1	20.59	3.49	355.50
47.	15	7.62	3	1/4	1	18.81	2.498	669.40
48.	15	7.62	5	1/4	1	17.33	8.02	1021.30
49.	15	7.62	7	1/4	1	15.38	15.6	1355.40
50.	20	7.62	1	1/4	1	28.74	-	567.50
51.	20	7.62	3	1/4	1	34.70	-	878.00
52.	20	7.62	5	1/4	1	22.82	14.63	1220.60
53.	20	7.62	7	1/4	1	15.50	17.4	1367.70
54.	25	7.62	1	1/4	1	44.41	24.54	415.30
55.	25	7.62	3	1/4	1	48.31	24.63	770.80
56.	25	7.62	5	1/4	1	48.20	23.65	1056.30
57.	25	7.62	7	1/4	1	52.71	29.78	1365.10
58.	15	7.62	1	1/4	3	26.10	95.78	139.00
59.	15	7.62	3	1/4	3	18.30	92.35	308.10
60.	15	7.62	5	1/4	3	16.20	89.50	466.10
61.	15	7.62	7	1/4	3	14.50	86.20	555.00
62.	20	7.62	1	1/4	3	18.31	80.83	172.40
63.	20	7.62	3	1/4	3	12.41	78.24	391.30
64.	20	7.62	5	1/4	3	18.20	68.13	533.60
65.	20	7.62	7	1/4	3	-	-	591.90
66.	25	7.62	1	1/4	3	26.21	67.53	120.10
67.	25	7.62	3	1/4	3	24.71	67.17	277.20
68.	25	7.62	5	1/4	3	30.31	67.60	475.80
69.	25	7.62	7	1/4	3	46.61	72.73	570.10
70.	15	7.62	1	1/2	1	24.01	7.5	190.20
71.	15	7.62	3	1/2	1	15.21	40.82	446.40
72.	15	7.62	5	1/2	1	18.28	6.94	461.00
73.	15	7.62	7	1/2	1	15.09	2.16	479.00
74.	20	7.62	1	1/2	1	20.16	4.96	68.60

EXP NO.	$P_{APPLIED}$ PSI	pH	$t_{RESIDENCE}$ MINUTES	ROD DIA., IN	SLURRY CONC., %	DISCHARGE MASS, g	DISCHARGE MASS %	FILTRATE MASS, g
75.	20	7.62	3	1/2	1	16.41	4.32	191.00
76.	20	7.62	5	1/2	1	15.49	3.68	282.90
77.	20	7.62	7	1/2	1	15.19	4.61	352.60
78.	25	7.62	1	1/2	1	17.45	4.24	53.60
79.	25	7.62	3	1/2	1	14.58	4.46	158.20
80.	25	7.62	5	1/2	1	15.94	4.78	238.80
81.	25	7.62	7	1/2	1	15.32	3.98	326.40
82.	15	7.62	1	1/2	3	20.78	4.52	131.90
83.	15	7.62	3	1/2	3	19.96	5.16	274.00
84.	15	7.62	5	1/2	3	15.37	6.12	379.10
85.	15	7.62	7	1/2	3	16.52	5.81	396.20
86.	20	7.62	1	1/2	3	19.40	7.73	97.70
87.	20	7.62	3	1/2	3	20.87	8.96	210.30
88.	20	7.62	5	1/2	3	23.50	12.25	297.40
89.	20	7.62	7	1/2	3	21.45	12.63	349.30
90.	25	7.62	1	1/2	3	-	-	95.80
91.	25	7.62	3	1/2	3	-	-	207.60
92.	25	7.62	5	1/2	3	-	-	276.80
93.	25	7.62	7	1/2	3	-	-	342.20
94.	15	8.20	1	0	1	25.33	16.23	400.90
95.	15	8.20	3	0	1	28.13	18.57	841.10
96.	15	8.20	5	0	1	31.02	23.62	1000.40
97.	15	8.20	7	0	1	36.19	34.21	1126.40
98.	20	8.20	1	0	1	29.18	19.40	254.20
99.	20	8.20	3	0	1	21.11	15.33	515.10
100.	20	8.20	5	0	1	46.32	24.36	647.70
101.	20	8.20	7	0	1	42.51	29.71	1037.70
102.	25	8.20	1	0	1	35.21	21.68	381.30
103.	25	8.20	3	0	1	51.61	26.17	635.20
104	25	8.20	5	0	1	49.70	33.90	915.10
105.	25	8.20	7	0	1	53.52	37.03	1157.50
106.	15	8.20	1	0	3	24.16	18.74	290.30
107.	15	8.20	3	0	3	28.11	23.29	460.94
108.	15	8.20	5	0	3	22.20	35.55	708.55
109.	15	8.20	7	0	3	20.89	33.15	922.22
110.	20	8.20	1	0	3	15.82	21.14	210.60
111.	20	8.20	3	0	3	18.88	25.67	380.40
112.	20	8.20	5	0	3	21.33	34.20	572.20
113.	20	8.20	7	0	3	17.15	40.73	737.10
114.	25	8.20	1	0	3	25.03	33.33	240.50
115.	25	8.20	3	0	3	19.25	37.03	415.30
116.	25	8.20	5	0	3	23.04	40.21	660.60
117.	25	8.20	7	0	3	20.01	45.36	805.50

Note: Empty blocks in the table indicate that measurements were not obtained.

5.2 DISCUSSION

For comparison and discussion, the data from Table 5-1 are plotted in Figures 5-1 through 5-7. There are many factors that influence the reproducibility of the data. In particular, the thick viscous nature of the discharge material greatly affects how rapidly the material will discharge. In evaluating the data only general trends are considered.

Figures 5-1 through 5-4 plot the data of the mass percent of clay in the thickened discharge slurry as a function of applied pressure and cake growth residence time in the tube. Each figure plots data for the same water pH of 7.62 and for two inlet slurry concentrations of 1% and 3% by weight. The figures differ by the aluminum rod diameter inserted in the center of the tube; 0 inch (*i.e.* no rod), 1/8 inch, 1/4 inch, and 1/2 inch.

Figure 5-4 shows that the 1/2 inch aluminum rod significantly hamper the discharge slurry concentration compared to 0, 1/8, or 1/4 inch rods as shown in Figures 5-1 through 5-3. For the 0 and 1/8 inch rods the data appear to be very similar for the two inlet slurry concentrations. For the 1/4 inch rod very high concentrations were obtained for the inlet 3% slurry whereas the concentrations for the 1% slurry were slightly lower than in Figures 5-1 and 5-2. This latter observation may indicate that there is an optimum rod size. For the 0 inch rod the increase in residence time seems to improve the mass % of the discharged slurry. Finally, one would expect the applied pressure to affect the cake growth but the results are inconclusive.

The affect of pH on the slurry thickening can be observed by comparing the plots in Figures 5-5 and 5-1. The concentrations of the thickened slurries are in the same range. Figure 5-5 shows definite trends relating increases in applied pressure and/or increases in residence time to increases in the discharge concentration.

Perhaps a better measure of the thickening of the slurry is the amount of filtrate removed. Figure 5-6 plots the mass of filtrate that is removed from the slurry by flowing through the tube walls. The data shown in Figure 5-6 is for no aluminum rod (0 inch diameter). As expected the mass of filtrate increases with the residence time. Since most the data can be fitted to a straight line this suggests that the clay particles were not plugging the pores in the tube wall.

Similar plots to Figure 5-6 can also be made for the rest of the data. When we take the slope of these lines we get an estimate of the filtrate rate (mass per time). These filtrate rates are plotted in Figure 5-7 for all of the experiments as a function of the applied pressure and the rod diameter.

In Figure 5-7 we see that the filtrate rates are best for no rod in the tube and worst for the 1/2 inch rod. The applied pressure and inlet slurry concentration may have some effect on the filtrate rate but their influence is not very strong under these experimental conditions. Comparing the curves for the 0 inch rod and pH of 7.62 to pH of 8.2 indicates that the slurry with the pH of 7.62 had the best filtrate rates.

The conclusion from this data is that the filtration is best run with no aluminum rod and with tap water with pH of 7.62. The applied pressures in the range of 15 to 25 psi do not have a great effect on the thickening of the slurry though some of the data suggests that increasing the applied pressure and residence time increases the discharge concentration.. Also the process ran equally well with 1% or 3% slurries.

The purpose of this project is to prove that the concept of periodic pressure filtration does work to thicken clay slurries. This is proven by the experimental data which shows that the slurry can be thickened from 1 or 3% to an average of about 30% and as much as 90 % or greater (Figure 5-3) under the best conditions.

Time and resource constraints prevented exploring a wider range of design and operating conditions. One recommendation for future work is to vary the tube diameters, tube lengths, and discharge times. Also it is recommended that greater ranges in applied pressure and residence times be evaluated. Finally, the process should be tested on actual soils.

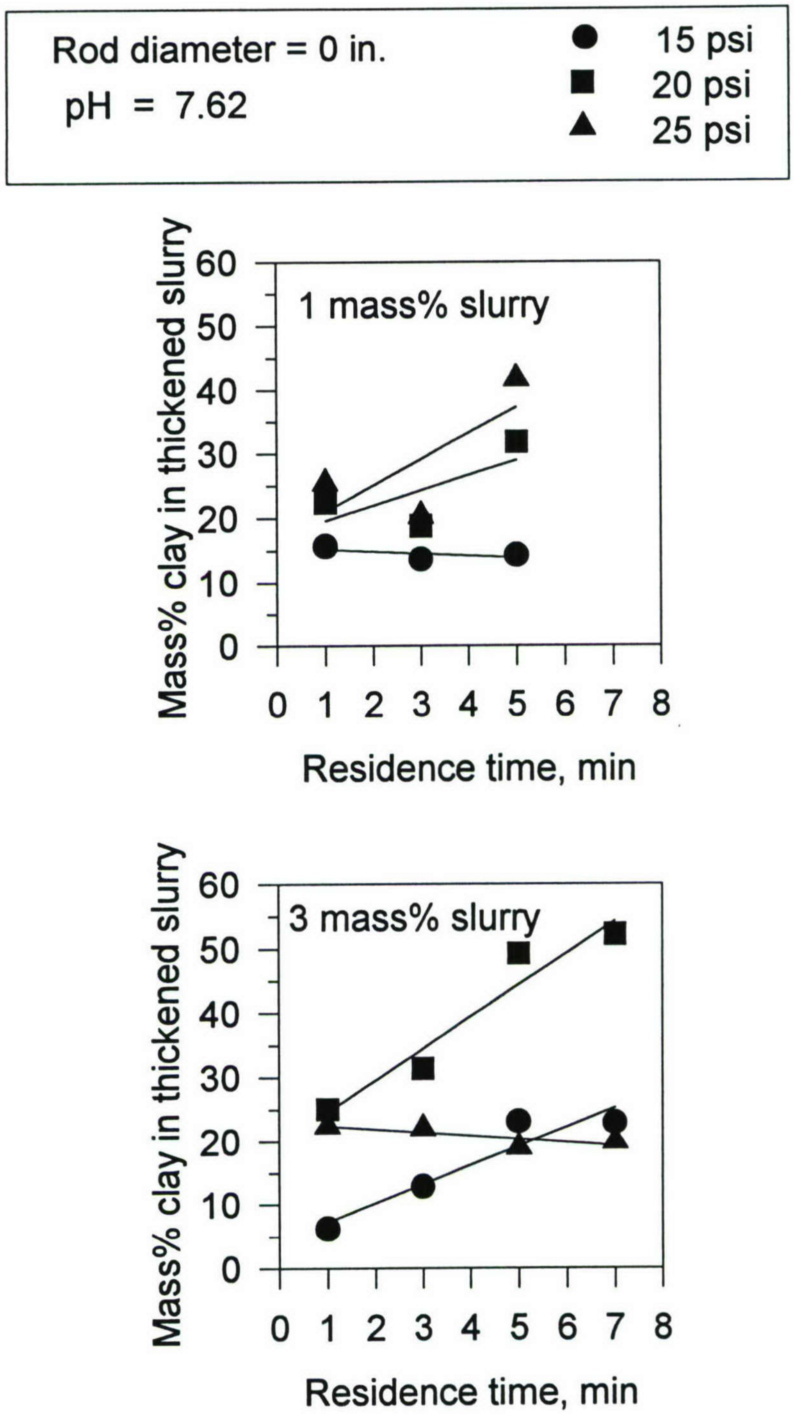

Figure 5-1. Plots of mass % of clay in the thickened discharge slurry as a function of residence time and applied pressure for inlet slurry concentrations of 1 and 3 % by mass. The data is for a slurry of pH of 7.62 and rod diameter of 0 inches (*i.e.* no rod).

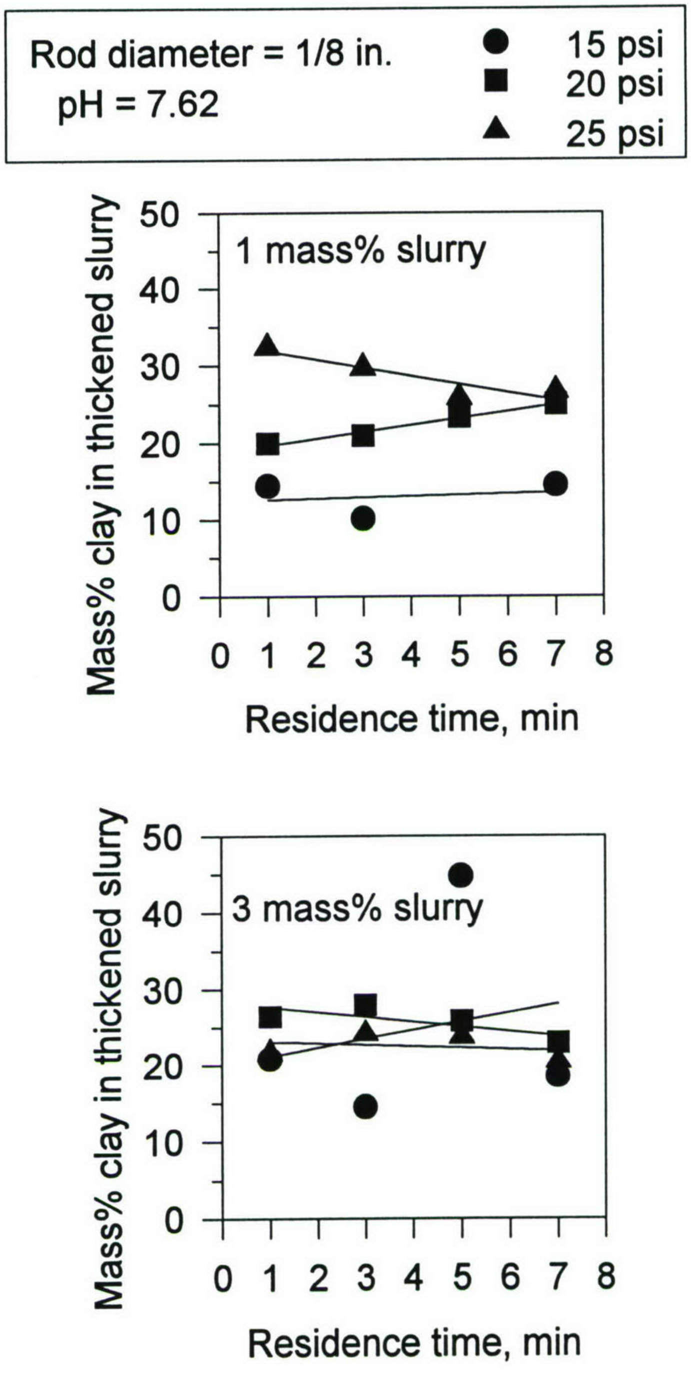

Figure 5-2. Plots of mass % of clay in the thickened discharge slurry as a function of residence time and applied pressure for inlet slurry concentrations of 1 and 3 % by mass. The data is for a slurry of pH of 7.62 and rod diameter of 1/8 inches.

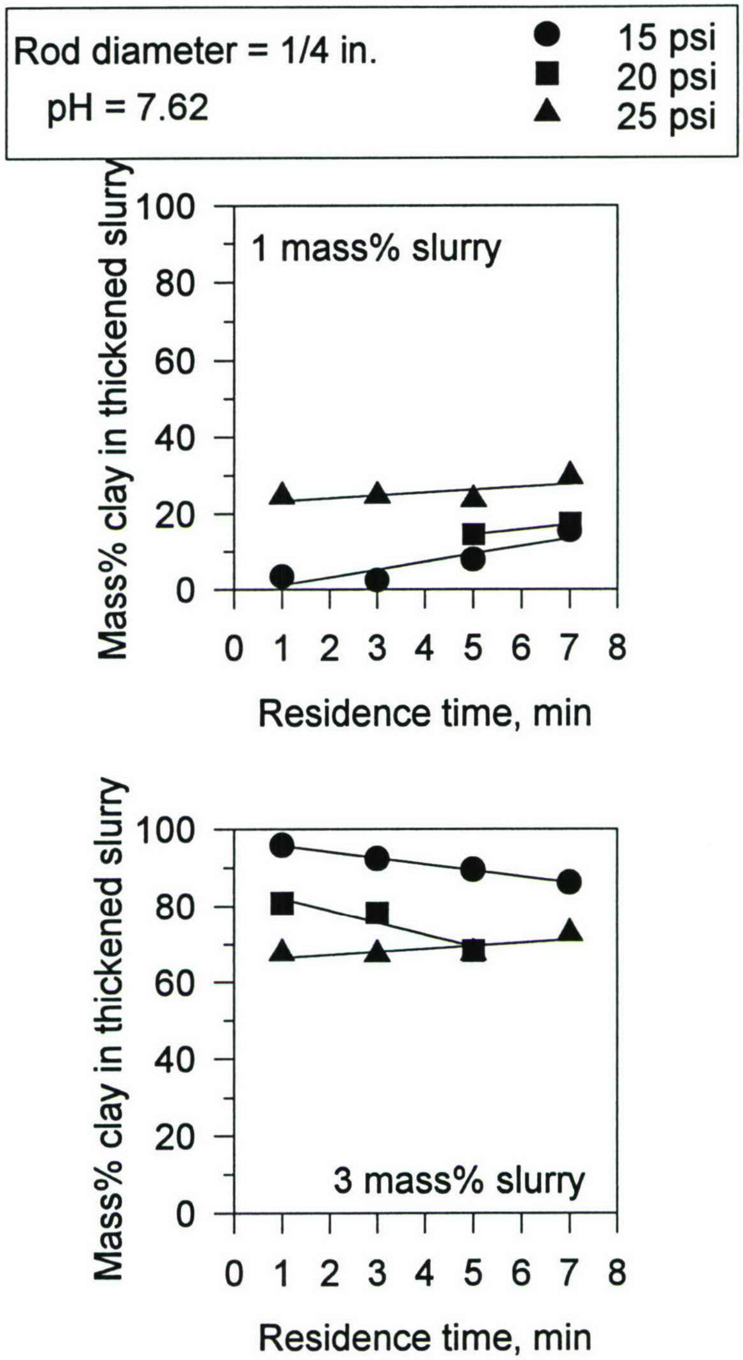

Figure 5-3. Plots of mass % of clay in the thickened discharge slurry as a function of residence time and applied pressure for inlet slurry concentrations of 1 and 3 % by mass. The data is for a slurry of pH of 7.62 and rod diameter of 1/4 inches.

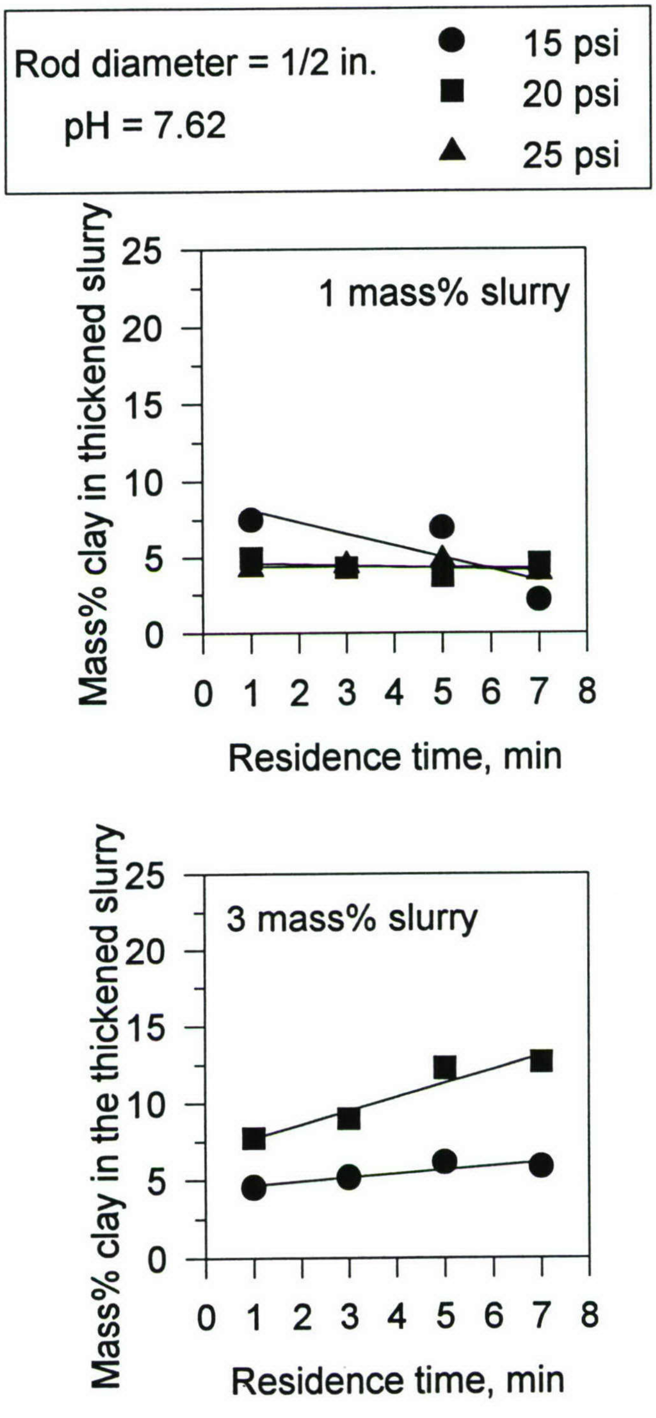

Figure 5-4. Plots of mass % of clay in the thickened discharge slurry as a function of residence time and applied pressure for inlet slurry concentrations of 1 and 3 % by mass. The data is for a slurry of pH of 7.62 and rod diameter of 1/2 inches.

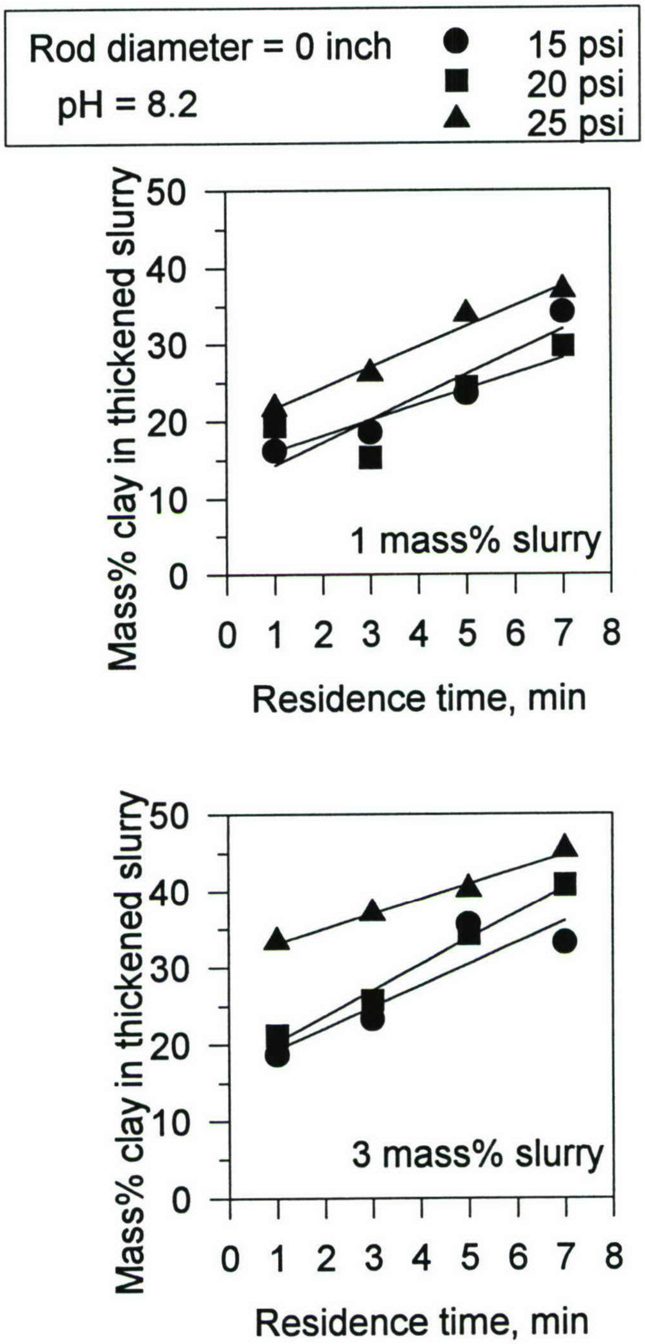

Figure 5-5. Plots of mass % of clay in the thickened discharge slurry as a function of residence time and applied pressure for inlet slurry concentrations of 1 and 3 % by mass. The data is for a slurry of pH of 8.2 and rod diameter of 0 inches (*i.e.* no rod).

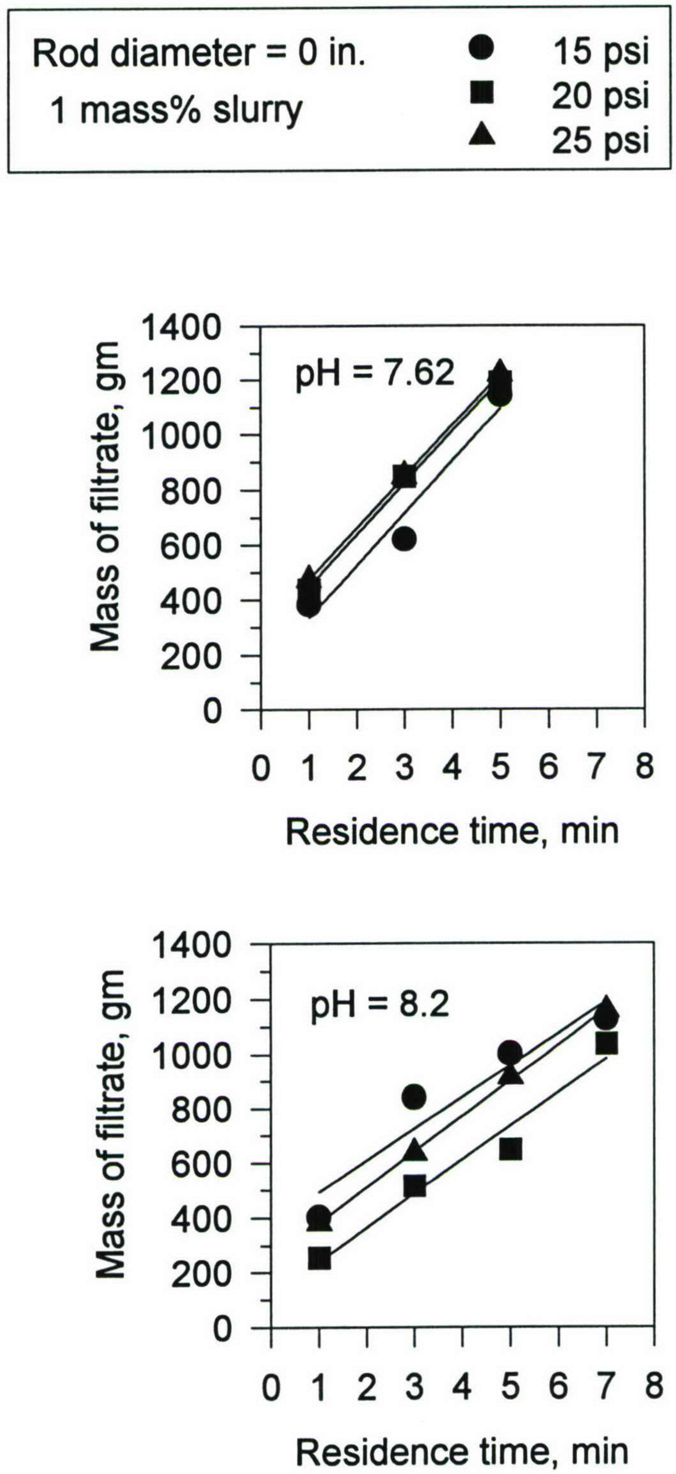

Figure 5-6. Plots of mass of filtrate removed from the filtering tube as a function of residence time and applied pressure for the experiments with 0 rod diameter (no rod), 1 % by mass of inlet slurry, and for pH of 7.62 and 8.2.

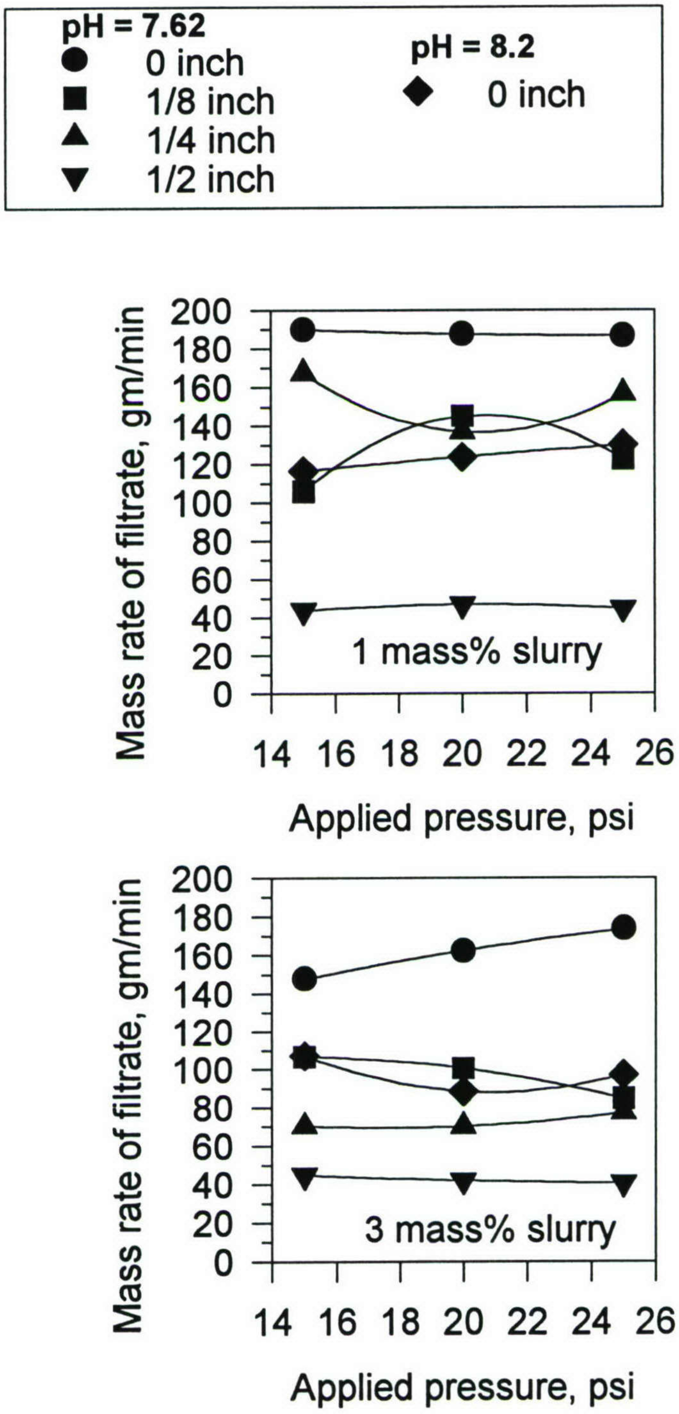

Figure 5-7. Plots of mass rate of filtrate from the filtering tube as a function of applied pressure and rod diameter for inlet slurry concentrations of 1 and 3 % by mass.

SECTION 6

SCALE-UP AND DESIGN

Scale-up and design of the periodic pressure filtration process goes hand-in-hand with a cost estimate of the process. The cost estimate made here is to provide an order of magnitude comparison for selection of thickening equipment. This cost estimate is based on the materials and equipment cost for the experimental setup described in Section 4. The costs are only for materials and equipment and do not include operation expenses, labor or maintenance costs.

Scale-up of the periodic pressure filtration process is linear in the number of tubes. For example, suppose we want to process one ton of thickened slurry per day by a continuous operation. Using typical rates from the experimental data one tube would process

$$\left(\frac{40\text{ g thick slurry}}{5\text{ minutes residence time}}\right)X\left(\frac{60\text{ minute}}{\text{hour}}\right)X\left(\frac{24\text{ hours}}{\text{day}}\right)X\left(\frac{1\text{ pound}}{454\text{ g}}\right)=25.4\text{ pounds/ tube / day}$$

about 25 pounds of thickened slurry per day. One ton of thickened slurry per day would therefore require about 80 tubes. For 80 tubes the average filtrate rate would be about 80 times 150 g/minute or about 3 gallons per minute.

If the slurry is pumped through the filter instead of using an applied pressure, then we can estimate the size and quantity of pumps. The pump power is equal to the flow rate times the pressure drop. Using the 3 gallons per minute flow rate and a pressure drop of 25 psi, then the pump power required is 0.04 horsepower. As a conservative estimate, to overcome pipe losses and static head, lets assume a 1/2 horsepower pump.

Now we can make an estimate of the equipment and materials costs. These costs are summarized in Table 6-1.

Table 6-1. Estimated costs of materials and equipment for processing 1 ton per day of thickened slurry.

QUANTITY	ITEM	UNIT PRICE, $	SUB TOTAL, $
80	TUBES	45	3600
160	SOLENOID VALVES	160	25600
1	PUMP	300	300
NA	PIPING/FITTINGS	NA	2000
		TOTAL	31500

In Table 6-1 we see that the most significant cost for the process is due to the solenoid valves. If we had selected 1 minute of residence time for the operation and all other parameters were the same, each tube would produce 5 times as much thickened slurry discharge and so only 16 tubes would be required. Following a similar analysis the total cost would be about $8140, or about 1/4th the cost.

These costs can be compared to the costs of gravity thickeners. Mular[11] suggests that for a gravity thickener the cost is given by the formula

$$\text{cost} = a(x)^b$$

where a = 147, b = 1.38, x is the tank diameter of the gravity thickener, in feet (in a range of 10 to 225 ft), and cost is in dollars. Svarovsky (page 179)[4] estimates that a thickener of 4 to 10 square feet is required to thicken one ton per day of copper tailings. For 10 square feet a diameter of about 2 feet is required. Extrapolating the above formula down to this size gives a cost of about $ 500 in 1980 dollars. To correct this estimate to 1993 dollars we multiply by a factor of 1.1 for a cost of $550. If we try to worst case the process and assume that the clay would require a 10 feet diameter gravity settler (about 314 square feet) this is equivalent to a cost of about $3500 in 1980 or $3850 in 1993.

This shows that the periodic pressure filtration process is much more expensive than the typical gravity thickener. This means that the periodic pressure filter should be used only when the size of a gravity settler would be excessive.

SECTION 7

CONCLUSIONS AND RECOMMENDATIONS

The most important conclusion from this work is that the periodic pressure filtration process is much more expensive in terms of materials and equipment than a typical gravity thickener. Experimental data collected here was needed to determine the rate at which the process could thicken the clay slurries so that this cost estimate could be made.

The experiments show that the process does work. Typically, clay slurries can be thickened from 1 to 3 % by mass to about 30 or 40 %. Within the time and resource constraints only some of the operating and design parameters were varied. This process should be considered for thickening a slurry that would require an excessively large gravity settler. It is recommended that a more extensive investigation be conducted to evaluate the effects of different tube diameters, tube lengths, and discharge times as well as exploring wider ranges in residence time and applied pressure.

REFERENCES

1. C.R. Blodgett, "Ultrafiltration of Munition Wastes (HMX, RDX, and TNT)," US Army NATICK Research and Development Laboratories Report NATICK/TR-82/005, September 1981.

2. A.A. Balasco, "Laboratory-Scale Soil Washing Test on Rocky Mountain Arsenal Basin F Material," US Army Toxic and Hazardous Materials Agency Report AMXTH-TE-CR-88016, August 1988.

3. N.P. Cheremisinoff and D.S. Azbel, *Liquid Filtration*, Ann Arbor Science, Woburn, Massachusetts, 1983.

4. L. Svarovsky, *Solid-Liquid Separation*, 3ed, Butterworths, London, 1990.

5. J.D. Henry Jr. A.P. Lui, and C.H. Kuo, "A Dual Functional Solid Liquid Separation Process Based on Filtration and Settling," *AIChE J.*, **22**(3), 433-441, 1976.

6. W.L. McCabe, J.C. Smith, and P. Harriott, *Unit Operations of Chemical Engineering,* 5ed., McGraw-Hill, New York, 1993.

7. H.S. Muralidhara, *Solid/Liquid Separation*, Battelle Press, Columbus, Ohio, 1989.

8. J.M. Coulson, J.F. Richardson, J.R. Backhurst, and J.H. Harker, *Chemical Engineering: Particle Technology and Separation Processes,* 4ed., Pergamon Press, Oxford, 1991.

9. L. Svarovsky, *Solid-Liquid Separation Processes and Technology*, Elsevier, Amsterdam, 1985.

10. S.Y. Baghdikian, M.M. Sharma, and L.L. Handy, "Flow of Clay Suspensions Through Porous Media," *SPE Reservoir Engineering*, **4**(2), 213-220, 1989.

11. A.L.Mular, "The Estimation of Preliminary Capital Costs," in *Mineral Processing Plant Design,* 2ed (A.L. Mular and R.B. Bahappu, Eds), pp 52-70, Soc. Mining Engineers, SME AIME, 1980.